PASSIVE FILTERS

BY PAUL G. SCHREIER, WA1TWT

If you know how filter components operate and can recognize several basic configurations, filter classification becomes simple

Filters may look complicated when you see them hidden in a maze of components on a schematic, but they're as simple as the few elements that they include. If you realize that capacitors do nothing more than block dc and pass high frequencies, and that inductors merely block high frequencies while passing dc and low ac frequencies, you can understand any passive filter's fundamental building blocks and its operating principles.*

Signals always take the easy way out

Suppose you're working with a signal generator that delivers all frequencies but you want only a certain frequency group to reach the load (**Fig. 1**). You can do this by making a low-resistance path for the unwanted frequencies to bypass the load — remember, any signal takes the path of least resistance.

First, use a capacitor as the bypass element (**Fig. 2A**). Because capacitors have a low impedance for high frequencies, those signals return to the signal source without going through the load; the load sees only low-frequency signals. This simple lowpass filter is called a shunt-capacitor filter because the capacitor "shunts" (or shorts) high frequencies around the load.

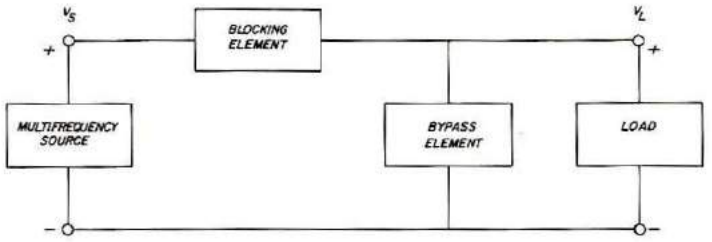

Fig. 1. This generalized configuration describes almost any filter. The source sends out all frequencies; only those not blocked by the blocking element or shorted by the bypass element reach the load. Proper selection of these elements determines the filter characteristics.

There's another easy way to help keep high frequencies away from the load. Instead of making it easy for them to

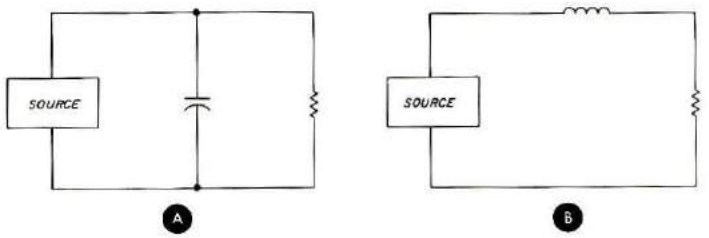

Fig. 2. The simple lowpass filter. The circuit in **A** uses a single capacitor to shunt high frequency signals around the load; the inductor in **B** blocks low frequencies from getting to the load.

*See "Understanding Resistors, Capacitors and Inductors," *Ham Radio Horizons*, December, 1977, page 46.

avoid the load, make it tough for them to get there. Inductors, you remember, block high frequencies; a configuration that puts one in series with the load also acts as a lowpass filter (**Fig. 2B**).

Note in both cases that neither filter works perfectly; some unwanted power does reach the load, but it has been greatly reduced.

If you want better filtering, it makes sense to combine these components. **Fig. 3** shows some popular configurations. First, you can hook them in the obvious LC-filter configuration

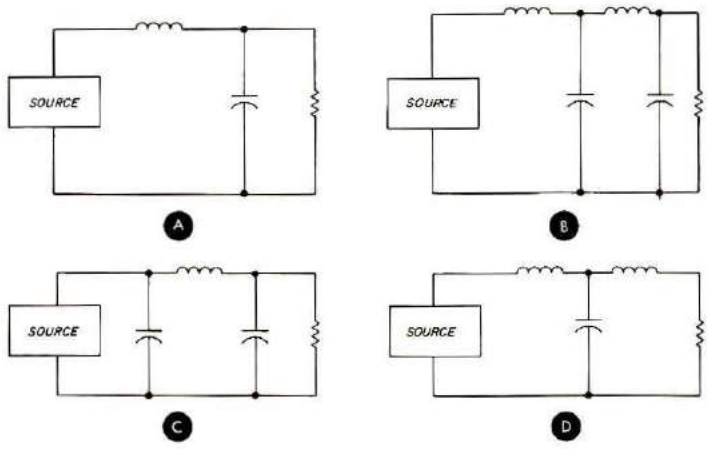

Fig. 3. Combine the elements in **Fig. 2** to produce a more efficient filter. Part **A** shows an LC filter while **B** shows a two-section LC; **C** illustrates a *pi*-section configuration while **D** is a T-section filter.

of **Fig. 3A**; a second section (**Fig. 3B**) makes the filter even more efficient. By taking a standard LC combination and adding an input capacitor you create the commonly seen *pi*-section filter (**Fig. 3C**); you can easily remember its name by its shape — it resembles the Greek symbol whose name it carries. Similarly, you can form a T-section filter (**Fig. 3D**) by adding another inductor.

Aren't all these designs redundant?

You're probably wondering if there's much difference in all these configurations. The filter's efficiency obviously depends on component values and the number of components; but there's something else, too. Some filter types operate better than others under various load conditions. For example, a shunt-capacitor filter (and, to some extent, other capacitor-input configurations) passes more high frequencies when load current increases, but adding an inductor helps negate this effect. Input-capacitor sections also let you put a higher voltage on the load. (For a detailed discussion of such effects, see Reference 1.)

Most ham junkbox circuits don't have physical size as a design constraint and you can use inductors liberally for good filtering. But what can a semiconductor manufacturer do if he wants to put a lowpass filter on an IC chip? — it's tough to use inductors in that situation.

Another design, the RC filter (**Fig. 4**), solves this problem because it's easy to implement both capacitors and resistors on integrated circuit chips. This method, however, has one drawback: the series resistor in the filter section eats up part of the source's energy; thus, less gets delivered to the load. Circuits that have *small* steady-current loads can live with that restriction, though. And, as before, you can add more sections to improve the filtering (or removal) of high-frequency components; but don't forget to watch that

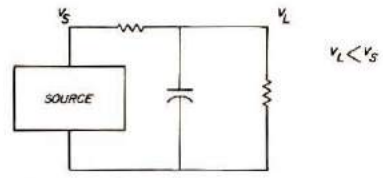

Fig. 4. RC filters eliminate inductors, but at the price of dissipating source energy, at all frequencies, through the series resistor element.

increased internal voltage drop across the filter caused by the series resistor. If your application calls for a load voltage lower than the source voltage, you'll undoubtedly go this route.

Learn to read any filter chart

Now that you understand how a lowpass filter works and what it does, let's examine the results graphically. **Fig. 5** is a frequency diagram for a lowpass filter. Note that as the desired frequency increases beyond a certain point, filter output to the load decreases. The frequency at the knee of this curve (where it begins to dip) carries the designation "cutoff frequency," or f_c. This point divides the frequency spectrum into two segments: the passband, to the left, where lower frequencies pass through to the load unattenuated, and the stop band, to the right, where higher-frequency signals see some resistance.

Of course, each filter has its own unique frequency diagram. Component values set f_c, and the number of filter components and sections dictates the slope of the attenuation curve — more elements make for a

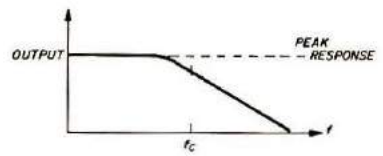

Fig. 5. This frequency diagram shows that in lowpass filters low frequencies encounter almost no resistance, while high frequencies are attenuated greatly. The cutoff frequency, f_c, shows where response begins to change. Note that this graph is only qualitative and merely gives a rough indication of filter performance.

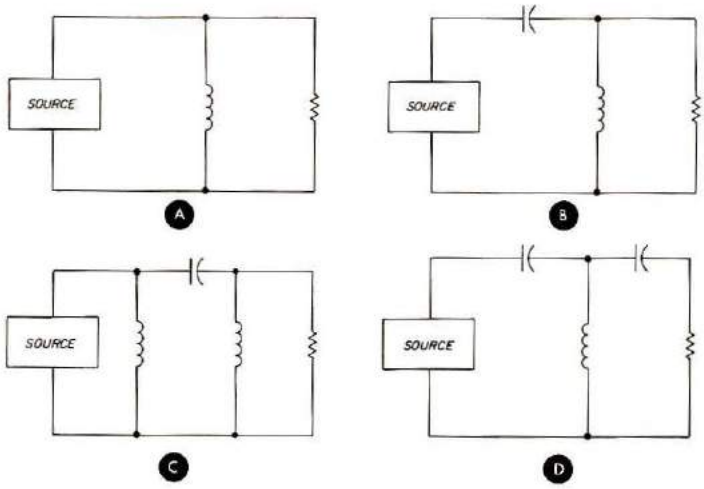

Fig. 6. These simple highpass filters use an inductor to short low frequencies (**A**); adding a capacitor helps by blocking high frequencies (**B**); while another input inductor makes a *pi*-section configuration (**C**). **D** shows a capacitor input T-section highpass filter.

sharper dropoff. Such diagrams are helpful, because in an instant you can tell what kind of filter you're dealing with and can decide if it will help you in your circuit design.

Highpass reverses the procedure

Let's go back to our original bypass element, but instead of a capacitor, we'll use an inductor (**Fig. 6A**). Knowing that inductors pass low frequencies with ease, you should quickly realize that this configuration forms a highpass filter. Once again, let's block these low frequencies from the load as well as shunting them around the load; use a capacitor for that blocking (**Fig. 6B**).

Highpass filters also come in other now-familiar configurations such as the *Pi* section (**Fig. 6C**) and *T* section (**Fig. 6D**). Don't look for IC manufacturers who use RL filters; common sense tells us that RL filters do little to save space because you can't miniaturize inductor coils to the chip level.

Highpass filters have frequency diagrams such as that in **Fig. 7**. The stop band lies to the left while the passband now sits to the right of f_c.

Just for fun, let's place both a capacitor and an inductor as shunt elements in our bypass element around the load (**Fig. 8A**). Seems silly? Will the two effects cancel each other? Not at all — take a minute to think about what those elements actually do. The capacitor shorts high frequencies, so the load never sees them, while the inductor does the same to low frequencies. But a certain range of middle frequencies gets sent to the load, hence the name bandpass filter for this arrangement.

Over the years, filter designers have come up with a number of configurations that work well in various bandpass situations. For a quick look at these see **Fig. 8B-C**; for a more detailed look, see Reference 2. But in all of them, note the use of inductors and capacitors together to block or short extreme frequency ranges, leaving the middle frequencies for the load.

Let's look at the frequency diagram of a bandpass filter (**Fig. 9**). Here you'll see a band of mid-range frequencies making up the passband and

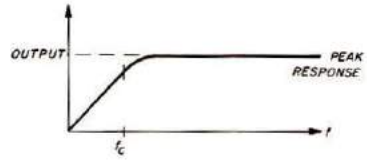

Fig. 7. Highpass filters have a frequency diagram that looks like a mirror image of lowpass filters.

either end constituting sections of the stop band. You might also assume that this diagram describes a shunt filter such as that in **Fig. 8A** with the inductor determining f_{c1} (shorting low frequencies) and the capacitor across the load determining f_{c2} (shorting high frequencies). But realize that many other configurations could have this identical frequency diagram.

In bandpass cases we can also define the filter bandwidth, the measure of the span of frequencies in the passband.

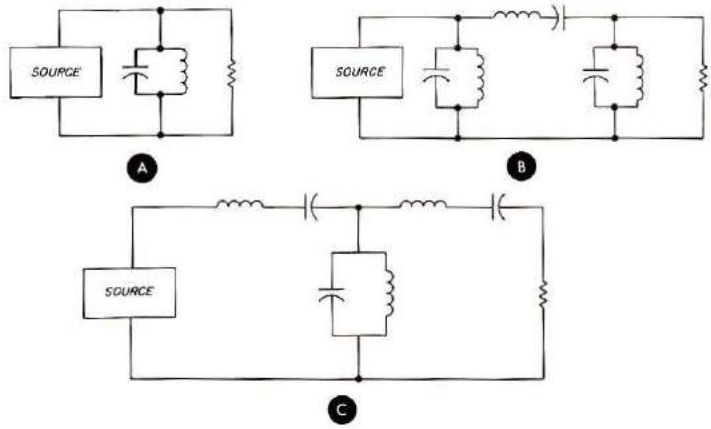

Fig. 8. Bandpass filters join capacitors and inductors in the bypass element (**A**), to form *pi*-section filters, (**B**), as well as T-section filters (**C**).

Look at those points where V_{out} is larger than $1/\sqrt{2}$ (or 0.707) of its maximum value; the distance between these two points defines the filter bandwidth.

Just remember what each component does

Armed with this knowledge, you should be able to pick up any analog circuit schematic and instantly recognize filter configurations, even if you

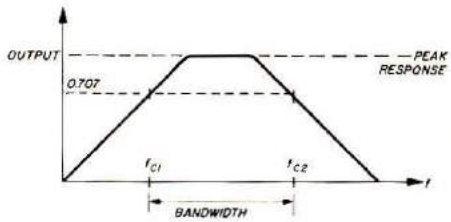

Fig. 9. Frequency diagrams for bandpass filters contain two cutoff frequencies. You can measure bandwidth by looking for those points where signal strength drops to 0.707 of maximum and determining the frequency spread between them.

can't instantly determine their cutoff frequencies. For instance, look for lowpass filters in power supplies, where you want to filter out high-frequency ripple from the dc you just smoothed out from the ac-line power. Look for highpass filters between amplifier sections where you want to amplify information — high frequencies — but not any dc that may have sneaked into the signal, through bias power, for example. Finally, you'll often find mid-range filters in tuning sections where you want only a specific range of signals sent through to later detector and amplifier stages.

References

1. John D. Ryder, *Electronic Fundamentals and Applications*, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1970.
2. *The Radio Amateur's Handbook*, American Radio Relay League, Newington, Connecticut, 1977.

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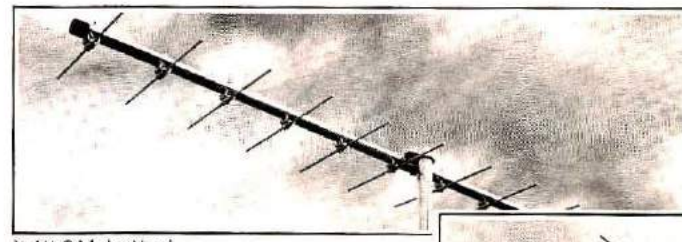

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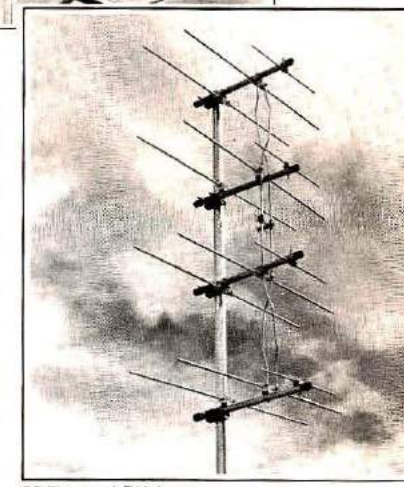

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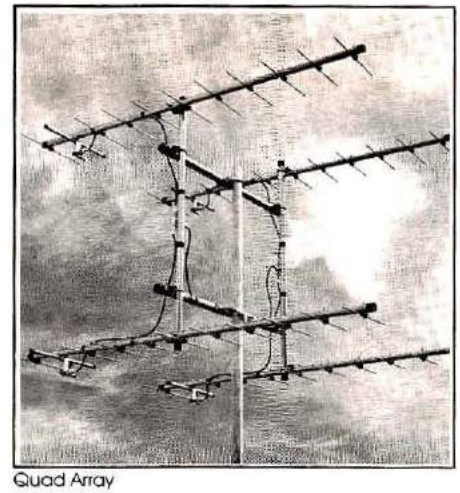

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